POTENTIAL STUDY OF PHOTOVOLTAIC POWER STATIONS TO MEET THE ENERGY NEEDS OF FUEL CELL UNITS IN BARU PANDANSIMO BEACH OF BANTUL, YOGYAKARTA

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Abstract

Energy needs are increasing rapidly along with population growth, increasing population activity, and massive development in technology. However, a current energy source is mainly from fossil energy. This condition is inversely proportional to fossil energy stock, decreasing year by year as a natural condition of non-renewable energy. On the other hand, fossil energy damages the environment by its pollution, such as deforestation and air and atmospheric pollution in the form of greenhouse gas emissions. For this reason, the world needs another source of energy that could replace fossil energy as a source and is also environmentally friendly. New and renewable energy could be the solution.

Indonesia has plenty amount of new and renewable energy potential. However, renewable energy is weather-dependent, thus requiring storage technology to store the energy. The current common storage technology is battery technology. This technology has some weaknesses: limited capacity, high cost, less flexibility, expensive, and short lifetime. Another storage technology with high flexibility, easy transport, high amount capacity, long lifetime, and wide usage is needed. Hydrogen storage appears to meet all these requirements.

This study aimed to calculate the optimum potential of photovoltaic power stations at Baru Pandansimo Beach of Bantul, Yogyakarta, as an energy source to produce hydrogen as a storage energy system. The simulations are done using HOMER software were carried out in three photovoltaic power station scenarios: fixed-tilt, single-axis tracker, and dual-axis tracker, and showed that the fixed-tilt photovoltaic power station scenario is the most optimal design and architecture. With total capacity reaching 7.8 MWp potential to be built at Baru Pandansimo, it could generate 11,657,704 KWh/year electrical energy with an NPC value of USD 8.29 M, and a COE of 0.0420 USD/KWh. This electrical energy could produce 213,288.06 kilograms of H2 at a 2.3 USD/kg production cost.

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1. Introduction

Nowadays, fossil energy and electricity are primary needs that must be met to support daily life. Increasing population, technological developments, and increasing community activities demand a massive increase in energy use. Unfortunately, in Indonesia, the majority of electrical energy is still generated from processing fossil fuel-based energy, which is non-renewable energy. With the increase in population, technological developments, and increased community activities, the use of fossil energy has increased drastically.

Data from The National Study of Energy Used in 2016 shows that energy used is still dominated by fossil energy (ESDM, 2017). The composition of the energy mix is petroleum 41.73%, coal 30.48%, natural gas 23.37%, hydropower 2.89%, geothermal 1.37%, and biofuel 0.165%. In total, the use of new and renewable energy in 2016 was only 4.42%. From these data, it can be concluded that the fulfillment of energy at this time is still very dependent on fossil energy. This is inversely proportional to the production of fossil energy in Indonesia.

From the 2018 Annual Report of the Directorate General of Oil and Gas, it is known that in 2008, oil reserves in Indonesia were 8.21 billion barrels, while in 2018, oil reserves were 7.5 billion barrels. From these data, it is proven that Indonesia's oil reserves are decreasing from year to year. Meanwhile, natural gas reserves in Indonesia have also reduced, from the initial 170 TSCF in 2008 to 136 TSCF in 2018. This value will continue to decline year after year transiently because it is due to reserves being depleted and increasing use due to the increasing number and activity of the population.

In addition to declining reserves, fossil energy also harms the environment. One of them is greenhouse gases. According to data from the 2018 Ministry of Environment and Forestry, fossil energy has a 48% share in producing total greenhouse gases in Indonesia. Therefore, it is necessary to have a new energy source that is environmentally friendly and can replace fossil energy in meeting energy needs in Indonesia.

One of the expected solutions is to develop new and renewable energy. This process has been initiated by the Government of Indonesia, following the Minister of Energy and Mineral Resources Regulation no. 39 of 2017, concerning the Implementation of Physical Activities and Utilization of New and Renewable Energy and Energy Conservation. In the utilization of new and renewable energy, the government targets a total of 23% to use new and renewable energy from the total national energy mix by 2025.

Indonesia is a country with great renewable energy potential, but has not fully explored yet, for supplying new and renewable energy, such as, among others, solar energy. Baru Pandansimo Beach, Bantul, Yogyakarta, is one of the locations in Indonesia that has utilized the potential of solar energy. It has an area of 24 hectares, with average solar energy radiation of 4.8 KWh/m^2/day (ESDM, 2012). The photovoltaic power station capacity already available there when this study ran was 27 KWp, which was considered not optimal, thus requiring a study to determine its optimal potential.

Another obstacle in using new and renewable energy is its discontinuousness, thus requiring storage media. The battery, which has several drawbacks, including its high price, short lifetime, and lack of flexibility, has been the commonly used storage media. Meanwhile, another storage system has high flexibility in storage, transportation, and utilization. It is hydrogen (Nicita et al, 2020).

As a means of energy storage and transportation, hydrogen can be produced using an unlimited number of raw materials, namely seawate. It used new and renewable energy as a source of electrolysis energy to produce hydrogen. So, that it is very possible to become an environmentally friendly energy source (Bhattacharyya et al, 2017).

The study of optimizing the use of solar energy at Baru Pandansimo Beach was carried out using the HOMER software to determine the optimal potential of the photovoltaic power station, both in terms of electricity production and economic aspects. The purpose of this research was to optimize the photovoltaic power station using the Sun-tracking system method, analyze techno-economics in their development and operation, and use them as input energy for the electrolysis of water into hydrogen gas.

This research was expected to provide benefits that are providing information on the optimal operating conditions for the photovoltaic power station in Baru Pandansimo Beach of Bantul, Yogyakarta. It provides information related to their development technology in the area and the achievable potential for producing hydrogen from the electrolysis of water using the power generated.

2. Methodology

Figure 1 shows the flowchart of the stages done in this research.

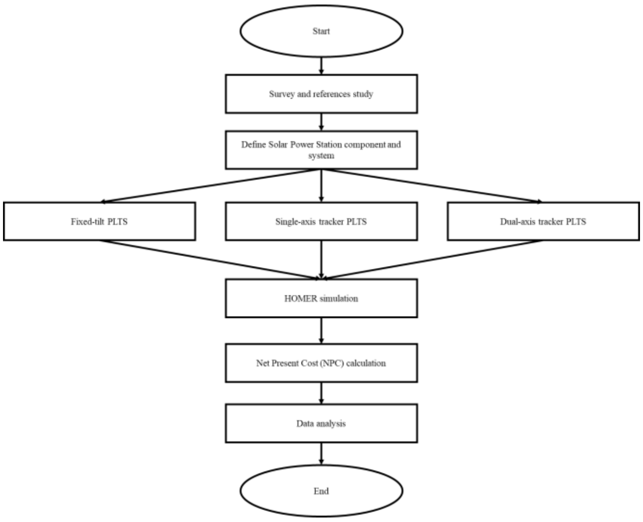


Figure 1. Research flowchart

A. Data Collection Method

In this study data were collected through the following methods:

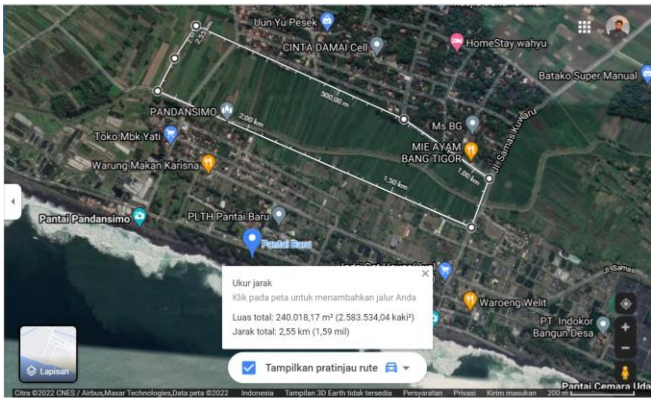
a. Direct observation at Baru Pandansimo Beach of Bantul, Yogyakarta.
b. Collecting secondary data from reference books, journals, and the internet, related to the research topic.
c. Retrieving data from the HOMER software database.

B. Research Location

This research was conducted at Baru Pandansimo Beach of Bantul, Yogyakarta, which is located at coordinates 07°59’02.62” S 110°12’ 33.71” E, as shown in Figure 2.

Figure 2. Location of Baru Pandansimo beach of Bantul, Yogyakarta

Pandansimo Baru Beach of Bantul has an area of 24 hectares with boundaries, as shown in Figure 3.



Ukur jarak

Klik pada peta untuk menambahkan jalur Anda

Luas total: 240.018,17 m² (2.583.534,04 kaki²)

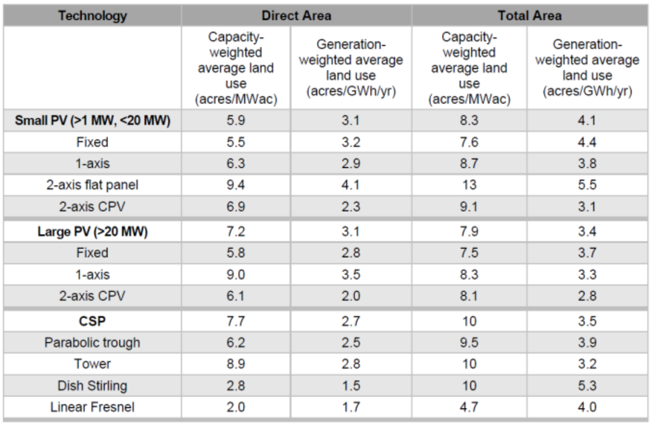
Jarak total: 2,55 km (1,59 mil)

☑ Tampilkan pratinjau rute

Figure 3. The boundaries of the area of Baru Pandansimo beach of Bantul, Yogyakarta

The National Renewable Energy Laboratory (NREL) has collected and analyzed data on land use to construct a photovoltaic power station based on different capacities and types, as listed in Table 1.

Table 1. Summary of the need for land area for the construction of a photovoltaic power station (NREL, 2013)



Technology	Direct Area		Total Area	
	Capacity-weighted average land use (acres/MWac)	Generation-weighted average land use (acres/GWh/yr)	Capacity-weighted average land use (acres/MWac)	Generation-weighted average land use (acres/GWh/yr)
Small PV (>1 MW, <20 MW)	5.9	3.1	8.3	4.1
Fixed	5.5	3.2	7.6	4.4
1-axis	6.3	2.9	8.7	3.8
2-axis flat panel	9.4	4.1	13	5.5
2-axis CPV	6.9	2.3	9.1	3.1
Large PV (>20 MW)	7.2	3.1	7.9	3.4
Fixed	5.8	2.8	7.5	3.7
1-axis	9.0	3.5	8.3	3.3
2-axis CPV	6.1	2.0	8.1	2.8
CSP	7.7	2.7	10	3.5
Parabolic trough	6.2	2.5	9.5	3.9
Tower	8.9	2.8	10	3.2
Dish Stirling	2.8	1.5	10	5.3
Linear Fresnel	2.0	1.7	4.7	4.0

Table 1 shows that constructing a fixed-tilt, single-axis tracker, or dual-axis tracker photovoltaic power station needs 7.6, 8.7, and 13 acres, respectively. Baru Pandansimo Beach of Bantul, Yogyakarta, has an area of 24 hectares or 59.26 acres (1 acre = 0.405 hectares). The potential capacities of each of the above types are 7.8 MWp, 6.8 MWp, and 4.5 MWp, respectively.

Data on solar energy radiation, namely the average data between 1983 and 2005 provided by NASA, are downloadable from the HOMER software. Clearness index data are also available. Table 2 and Figure 4.3 show both data of the area of Baru Pandansimo Beach of Bantul, Yogyakarta.

Table 2. Data of solar energy radiation and clearness index at Baru Pandansimo Beach of Bantul, Yogyakarta

Month	Clearness Index	Average Daily Radiation (KWh/m^2/day)
January	0.396	4.28
February	0.413	4.47
March	0.437	4.59
April	0.485	4.72
May	0.534	4.73
June	0.544	4.55
July	0.561	4.8
August	0.564	5.25
September	0.546	5.54
October	0.506	5.39
November	0.437	4.71
December	0.425	4.57
Average	**0.487**	**4.8**

The HOMER software provides data on the temperature of the research site in the form of average data for measurements made by NASA from 1984 to 2013. Table 3 is temperature data of Baru Pandansimo Beach of Bantul, Yogyakarta.

Table 3. Average temperature at Baru Pandansimo Beach of Bantul, Yogyakarta

Month	Temperature (^{o}C)
January	24.97
February	24.99
March	25.19
April	25.34
May	25.04
June	24.3
July	23.62
August	23.72
September	24.63
October	25.36
November	25.35
December	25.05
Average	**24.80**

3. Results and Discussion

From the data above, the simulation of optimizing a photovoltaic power station was carried out using the HOMER software by performing three scenarios based on the photovoltaic power station types, namely fixed-tilt, single-axis tracker, and dual-axis tracker. The components of the HOMER simulation are shown in Figure 4.

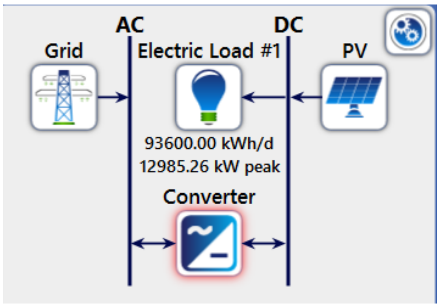


Figure 4. Photovoltaic power station configuration

A. Electric Load

To compare the performances and economic values of the three station types, a HOMER simulation was carried out with the same load and capacity values. The assumed load and capacity of 4.5 MW and 4.5 MWp, respectively, referred to the maximum potential capacity that could be built at the beach for the dual-axis type. The load in this simulation was only given during the hours when the power plant works, namely during the day, from 06:00 A.M. to 6:00 P.M. At 00:00 - 05:00 and 18:00 - 24:00, there is no load because the power plant does not work during these hours. The detailed data are presented in Table 4.

Table 4. HOMER simulation load data

Time	Load (MW)		
	Fixed Tilt PLTS (Maksimum 7.8 MWp)	Single-axis tracker PLTS (Maksimum 6.8 MWp)	Dual-axis tracker PLTS (Maksimum 4.5 MWp)
0:00	0	0	0
1:00	0	0	0
2:00	0	0	0
3:00	0	0	0
4:00	0	0	0
5:00	0	0	0
6:00	4.5	4.5	4.5
7:00	4.5	4.5	4.5
8:00	4.5	4.5	4.5
9:00	4.5	4.5	4.5
10:00	4.5	4.5	4.5
11:00	4.5	4.5	4.5
12:00	4.5	4.5	4.5
13:00	4.5	4.5	4.5
14:00	4.5	4.5	4.5
15:00	4.5	4.5	4.5
16:00	4.5	4.5	4.5
17:00	4.5	4.5	4.5
18:00	4.5	4.5	4.5
19:00	0	0	0
20:00	0	0	0
21:00	0	0	0
22:00	0	0	0
23:00	0	0	0

B. PV Module

The PV module used was the flat PV with the same specifications as those available in the market. The data were taken from the HOMER software database as presented in the following table:

a. Derating Factor : 85-96%
b. Efficiency : 15-17
c. Temperature effect : -0.53%/°C
d. Nominal operating cell temperature (NOCT) : 44°C
e. Lifetime : 20, 25, and 30 years

C. Converter

The converter in this study was used to convert DC electricity from PV to AC electricity to distribute excess electrical energy to the PLN network when excess production occurred. The converter specifications used in the simulation are as follows:

a. Type : DC to AC Generic Converter
b. Capacity : 1000 – 5000 KW
c. Efficiency : 98%
d. Lifetime : 15 years

D. Grid

In this simulation, the photovoltaic power station would be an on-grid type solar power station to supply or sell excess electricity production to the PLN network. According to the Minister of Energy and Mineral Resources No. 19 of 2016, the purchase price of electricity from the station is 0.145 USD/KWh.

E. Results of Simulation using the HOMER software

1. Fixed-tilt Photovoltaic Power Station

Table 5 presents the most optimal architecture, specifications, and economic value of the photovoltaic power station with fixed-tilt type based on the HOMER software.

Table 5. The architecture of a fixed-tilt photovoltaic power station

Project Lifetime (Years)	Capacity Shortage (%)	PV Time (Years)	PV Derating (%)	PV Efficiency (%)	PV Capacity (KW)	Grid (KW)	Converter (KW)	NPC ($)	COE ($)	Initial Capital ($)	O&M ($)	Capital Cost ($)	Production (KWh/yr)
20	100	30	96	17	4,500	0	1,000	4.91M	0.043	4.83M	71,750	4.77M	6,725,598

Table 5 shows that the optimal conditions for a fixed-tilt photovoltaic power station with a capacity of 4.5 MWp are obtained through the following configuration:

a. Project lifetime : 20 years
b. PV lifetime : 30 years
c. PV efficiency : 17%
d. Converter capacity : 1 MW

With this configuration, a fixed-tilt photovoltaic power station can generate electrical energy of 6,725,598 KWh/year. Its construction requires an initial cost of USD 4.83 M, with a Present Net Cost (NPC) of USD 4.91 M, an Operating and Maintenance (O&M) cost of 71,750 USD/year, and a Cost of Electricity (COE) value of 0.0430 USD/KWh.

2. Single-Axis Tracker Photovoltaic Power Station

Table 6 presents the most optimal architecture, specification, and economic value of a photovoltaic power station with the single-axis tracker type based on HOMER software.

Table 6. The architecture of a single-axis tracker photovoltaic power station

Project Lifetime (Years)	Capacity Shortage (%)	PV Time (Years)	PV Derating (%)	PV Efficiency (%)	PV Capacity (KW)	Grid (KW)	Converter (KW)	NPC ($)	COE ($)	Initial Capital ($)	O&M ($)	Capital Cost ($)	Production (KWh/yr)
20	100	30	96	17	4,500	0	1,000	5.23M	0.0415	5.15M	76,250	4.08M	7,417,558

Table 6 shows that the optimal conditions for a photovoltaic power station with the single-axis tracker type with a capacity of 4.5 MWp can be obtained with the following configuration:

a. Project lifetime : 20 years
b. PV lifetime : 30 years
c. PV efficiency : 17%
d. Converter capacity : 1 MW

With this configuration, a single-axis photovoltaic power station can generate electricity of 7,417,558 KWh/year. Its construction requires an initial cost of USD 5.15 M, with a Present Net Cost (NPC) of USD 5.23 M, an Operating and Maintenance (O&M) cost of 76,250 USD/year, and a Cost of Electricity (COE) of 0.0415 USD/KWh.

3. Dual-Axis Tracker Photovoltaic Power Station

Table 7 presents the most optimal architecture, specifications, and economic value of a photovoltaic power station with a dual-axis tracker type based on the HOMER software.

Table 7. The architecture of a dual-axis tracker photovoltaic power station

Project Lifetime (Years)	Capacity Shortage (%)	PV Time (Years)	PV Derating (%)	PV Efficiency (%)	PV Capacity (KW)	Grid (KW)	Converter (KW)	NPC ($)	COE ($)	Initial Capital ($)	O&M ($)	Capital Cost ($)	Production (KWh/yr)
20	100	30	96	17	4,500	0	1,000	7.71M	0.0519	7.71M	107,750	7.65M	8,730,665

Table 7 shows that the optimal conditions for a dual-axis tracker photovoltaic ower station with a capacity of 4.5 MWp have the following configuration:

a. Project lifetime : 20 years
b. PV *lifetime* : 30 years
c. PV efficiency : 17%
d. Converter capacity : 1 MW

With this configuration, a dual-axis tracker photovoltaic power station can generate electrical energy of 8,730,665 KWh/year. Its construction requires an initial cost of USD 7.71 M, with a Present Net Cost (NPC) of USD 7.71 M, an Operating and Maintenance (O&M) cost of 107,750 USD/year, and a Cost of Electricity (COE) value of 0.0519 USD/KWh.

The simulation results show that among the three types of solar power stations with the same capacity, namely 4.5 MW. The dual-axis tracker type has the best performance by generating electrical energy of 8,730,665 kWh/year. It is followed by the single-axis tracker type, which generates electricity of 7,417,558 KWh/year, and finally, the fixed-tilt type, which produces 6,725,598 KWh/year electricity. From the simulation results above, it can be concluded that the dual-axis tracker type has the best ability to generate electrical energy.

From an economic perspective, of the three types, the fixed-tilt one has the best economic value with a Present Net Cost (NPC) of USD 4.91 M, followed by the single-axis tracker type with an NPC value of USD 5.23 M. Lastly, by the dual-axis tracker type with an NPC value of USD 7.71 M. For the value of Cost of Electricity (COE), the fixed-tilt type has a value of 0.043 USD/KWh. In contrast, the single-axis tracker type has a value of 0.0415 USD/KWh, and the dual-axis tracker type has 0.0519 USD/KWh.

The HOMER software refers to the lowest NPC value in selecting the most optimal type. The fixed-tilt type is the most optimal type to be developed in Baru Pandansimo Beach of Bantul, Yogyakarta.

4. Calculation of the Potential of a Fixed-tilt Photovoltaic Power Station at Baru Pandansimo Beach of Bantul, Yogyakarta

According to the availability of land at Baru Pandansimo Beach, the maximum capacity that can be built for a fixed-tilt photovoltaic power station is 7.8 MWp. Table 8 presents the HOMER software's optimal architecture, specifications, and economic value.

Table 8. The architecture of a fixed-tilt photovoltaic power plant with a capacity of 7.8 MWp

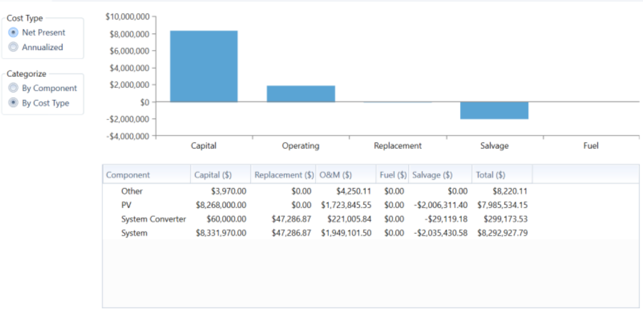
Project Lifetime (Years)	Capacity Shortage (%)	PV Time (Years)	PV Derating (%)	PV Efficiency (%)	PV Capacity (KW)	Grid (KW)	Converter (KW)	NPC ($)	COE ($)	Initial Capital ($)	O&M ($)	Capital Cost ($)	Production (KWh/yr)
20	100	30	96	17	7,800	0	1,000	8.29M	0.0420	8.33M	114,650	8.27M	11,657,704

From Table 8, it is known that the optimal conditions for a fixed-tilt photovoltaic power plant with a capacity of 7.8 MWp have the following configuration:

a. Project lifetime : 20 years
b. PV lifetime : 30 years
c. PV efficiency : 17%
d. Converter capacity : 1 MW

A fixed-tilt photovoltaic power plant can generate electrical energy of 11,657,704 KWh/year with this configuration. Its construction requires an initial cost of USD 8.33 M, with a Present Net Cost (NPC) of USD 8.29 M, an Operating and Maintenance (O&M) cost of 114,650 USD/year, and a Cost of Electricity (COE) of 0.0420 USD. /KWh. Based on the Minister of Energy and Mineral Resources Regulation No. 19 of 2016, the purchase price of electrical energy from PLTS is 0.145 USD/KWh. So, it will reach BEP in the 6th year of operation.

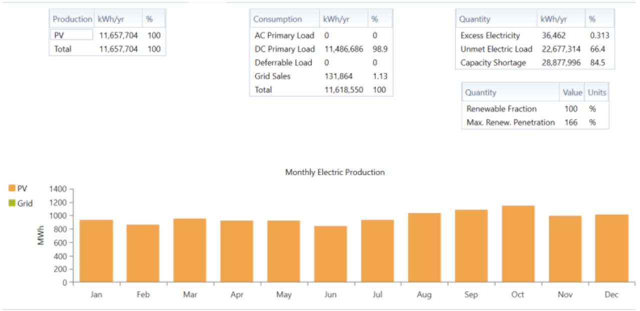
Figure 5 shows a breakdown of the costs of the components of a fixed-tilt photovoltaic power plant with a capacity of 7.8 MWp. The costs include Capital Cost, Replacement Cost, Operating and Maintenance Cost, capital cost, replacement cost, and salvage value.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Other	$3,970.00	$0.00	$4,250.11	$0.00	$0.00	$8,220.11
PV	$8,268,000.00	$0.00	$1,723,845.55	$0.00	-$2,006,311.40	$7,985,534.15
System Converter	$60,000.00	$47,286.87	$221,005.84	$0.00	-$29,119.18	$299,173.53
System	$8,331,970.00	$47,286.87	$1,949,101.50	$0.00	-$2,035,430.58	$8,292,927.79

Figure 5. Summary of a fixed-tilt photovoltaic power plant's costs

Figure 6 shows a breakdown of the production of electrical energy each month in outline. The lowest production of electrical energy occurs in June. The total electrical energy produced is 11,657,704 KWh/year.



Production	kWh/yr	%
PV	11,657,704	100
Total	11,657,704	100

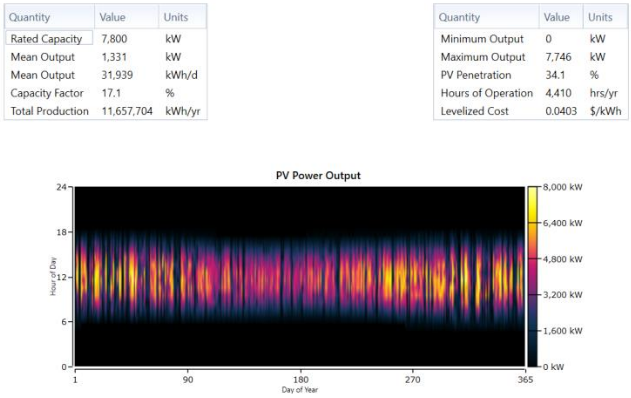
Consumption	kWh/yr	%
AC Primary Load	0	0
DC Primary Load	11,486,686	98.9
Deferrable Load	0	0
Grid Sales	131,864	1.13
Total	11,618,550	100

Quantity	kWh/yr	%
Excess Electricity	36,462	0.313
Unmet Electric Load	22,677,314	66.4
Capacity Shortage	28,877,996	84.5

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	166	%

Figure 6. The electrical energy produced by a fixed-tilt photovoltaic power plant with a capacity of 7.8 MWp

Figure 7 shows the electrical energy production data from the PV module. The average capacity of PV is 1.33 MW. The average electrical energy produced is 31,939 KWh/day.



Quantity	Value	Units
Rated Capacity	7,800	kW
Mean Output	1,331	kW
Mean Output	31,939	kWh/d
Capacity Factor	17.1	%
Total Production	11,657,704	kWh/yr

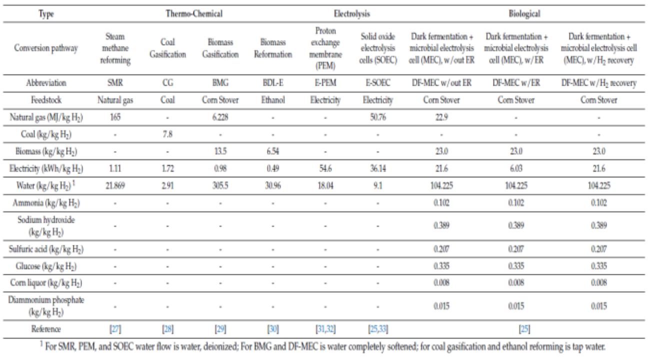
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	7,746	kW
PV Penetration	34.1	%
Hours of Operation	4,410	hrs/yr
Levelized Cost	0.0403	$/kWh

Figure 7. Electrical energy production by the PV module

5. Hydrogen Production Economic Calculation

Electrical energy from the photovoltaic power station will be used to produce hydrogen either as energy storage or as a means of energy transportation. According to Andi Mehmeti *et al*. (2018), to produce 1 kg of hydrogen using Proton Exchange Membrane (PEM) technology needs 54.6 KWh/kg of electrical energy, as shown in Table 9.

Table 9. Resources needed to produce hydrogen (Andi Mehmeti et al., 2018)



Type	Thermo-Chemical				Electrolysis		Biological		
Conversion pathway	Steam methane reforming	Coal Gasification	Biomass Gasification	Biomass Reformation	Proton exchange membrane (PEM)	Solid oxide electrolysis cells (SOEC)	Dark fermentation + microbial electrolysis cell (MEC), w/out ER	Dark fermentation + microbial electrolysis cell (MEC), w/ER	Dark fermentation + microbial electrolysis cell (MEC), w/H_2 recovery
Abbreviation	SMR	CG	BMG	BDL-E	E-PEM	E-SOEC	DF-MEC w/out ER	DF-MEC w/ER	DF-MEC w/H_2 recovery
Feedstock	Natural gas	Coal	Corn Stover	Ethanol	Electricity	Electricity	Corn Stover	Corn Stover	Corn Stover
Natural gas (MJ/kg H_2)	165	-	6.228	-	-	50.76	22.9	-	-
Coal (kg/kg H_2)	-	7.8	-	-	-	-	-	-	-
Biomass (kg/kg H_2)	-	-	13.5	6.54	-	-	23.0	23.0	23.0
Electricity (kWh/kg H_2)	1.11	1.72	0.98	0.49	54.6	36.14	21.6	6.03	21.6
Water (kg/kg H_2) [1]	21.869	2.91	305.5	30.96	18.04	9.1	104.225	104.225	104.225
Ammonia (kg/kg H_2)	-	-	-	-	-	-	0.102	0.102	0.102
Sodium hydroxide (kg/kg H_2)	-	-	-	-	-	-	0.389	0.389	0.389
Sulfuric acid (kg/kg H_2)	-	-	-	-	-	-	0.207	0.207	0.207
Glucose (kg/kg H_2)	-	-	-	-	-	-	0.335	0.335	0.335
Corn liquor (kg/kg H_2)	-	-	-	-	-	-	0.008	0.008	0.008
Diammonium phosphate (kg/kg H_2)	-	-	-	-	-	-	0.015	0.015	0.015
Reference	[27]	[28]	[29]	[30]	[31,32]	[25,33]	[25]		

[1] For SMR, PEM, and SOEC water flow is water, deionized; For BMG and DF-MEC is water completely softened; for coal gasification and ethanol reforming is tap water.

From the calculation data, the electrical energy produced by a fixed-tilt photovoltaic power plant is 11,657,704 KWh/year, and the electrical energy required to make 1 kg of hydrogen using Proton Exchange Membrane (PEM) Electrolysis is 54.6 KWh. Therefore, a fixed-tilt photovoltaic power plant's hydrogen generated from electrical energy is 213,511.06 kilograms per year. With a COE of 0.0420 USD/KWh, the cost to produce 1 kg of H2 is 2.3 USD/kg.

4. Conclusion

The dual-axis tracker photovoltaic power plant, based on the calculation, has the best electrical energy production performance compared to the single-axis tracker and the fixed-tilt ones. With the same capacity of 4.5 MWp, it can generate electrical energy of 8,730,665 KWh/year, while the single-axis tracker and the fixed-tilt can do 7,417,558 KWh/year 6,725,598 KWh/year, respectively.

The fixed-tilt photovoltaic power plant has the lowest NPC value of USD 4,91 M, making it the most optimal one to be developed at Baru Pandansimo Beach of Bantul, Yogyakarta. A single-axis tracker photovoltaic power plant, producing electrical energy of 11,657,704 KWh/year, can generate 213,511.06 kgs of H_2 with an economic value of 2.3 USD/kg.

References

ABB, 2010, *Technical Application Papers No. 10–Photovoltaic plants*.

Ali, A. M., Mustafa, S. S., and Mutlag, A. H., 2016, Design optimization of solar power system with respect to temperature and sun tracking. In *2016 Al-Sadeq International Conference on Multidisciplinary in IT and Communication Science and Applications (AIC-MITCSA)* (pp. 1-5). IEEE.

Balakrishnan, J., 2007, Fuel cell technology. *2007 Third international conference on Information and automation for sustainability* (pp. 159-164). IEEE.

Bhattacharyya, R., Misra, A., and Sandeep, K. C., 2017, Photovoltaic solar energy conversion for hydrogen production by alkaline water electrolysis: conceptual design and analysis. *Energy Conversion and Management*, 133, 1-13.

Cole, S., Van Hertem, D., Meeus, L., and Belmans, R., 2005, SWOT analysis of utility side energy storage of technologies. *5th WSEAS/IASME International conference on electric power systems, high voltages, electric machines* (pp. 16-18).

Esdm.go.id., 2012**,** Matahari untuk PLTS di Indonesia. Diakses pada 19 Januari 2020, dari https://www.esdm.go.id/id/media-center/arsip-berita/matahari-untuk-plts-di-indonesia.

ESDM. ,2017, *Kajian penyediaan dan pemanfaatan migas, batubara, EBT, dan listrik 2017*. Jakarta: Pusat Data Dan Teknologi Informasi Energi Dan Sumber Daya Mineral Kementerian Energi Dan Sumber Daya Mineral.

ESDM., 2017, Peraturan Menteri ESDM No. 39 Tahun 2017. *Pelaksanaan kegiatan fisik pemanfaatan energi baru dan energi terbarukan serta konservasi Energi.* Jakarta: Kementerian Energi Dan Sumber Daya Mineral Kementerian Energi Dan Sumber Daya Mineral.

ESDM., 2020, Startup EBT kian diminati, jenis energi ini banyak dilirik. Diakses pada 19 Januari 2020, dari https://www.esdm.go.id/id/media-center/arsip-berita/startup-ebt-kian-diminati-jenis-energi-ini-banyak-dilirik.

Fu, R., Feldman, D. J., and Margolis, R. M., 2018, *US solar photovoltaic system cost benchmark: Q1 2018* (No. NREL/TP-6A20-72399). National Renewable Energy Lab.(NREL), Golden, CO (United States).

Gilman, P., Lambert, T., 2006, *HOMER The Micropower Optimization ModelSoftware Started Guide*, *National Renewable Energi Laboratory of United States Government*.

Gultom, T. T., 2015, Pemanfaatan photovoltaic sebagai pembangkit listrik tenaga surya. *Journal Mudira Indure*, 1, 33-42.

KLHK**.**, 2018**,** *Laporan inventarisasi gas rumah kaca dan monitoring, Pelaporan verifikasi tahun 2018.* Jakarta: Kementerian Lingkungan Hidup dan Kehutanan, Direktorat Jenderal Pengendalian Perubahan Iklim, Direktorat Inventarisasi Gas Rumah Kaca, Monitoring, Pelaporan dan Verifikasi.

Mahendran, M., Ong, H. L., Lee, G. C., and Thanikaikumaran, K., 2013, An experimental comparison study between single-axis tracking and fixed photovoltaic solar panel efficiency and power output: Case study in east coast Malaysia. *Sustainable Development Conference, Bangkok, Thailand*.

Mehmeti, A., Angelis-Dimakis, A., Arampatzis, G., McPhail, S. J., and Ulgiati, S., 2018, Life cycle assessment and water footprint of hydrogen production methods: from conventional to emerging technologies. *Environments*, *5*(2), 24.

Myori, D. E., Mukhaiyar, R., and Fitri, E., 2019, Sistem tracking cahaya matahari pada photovoltaic. *INVOTEK: Jurnal Inovasi Vokasional dan Teknologi*, 19(1), 9-16.

Nicita, A., Maggio, G., Andaloro, A. P. F., and Squadrito, G., 2020, Green hydrogen as feedstock: Financial analysis of a photovoltaic-powered electrolysis plant. *International Journal of Hydrogen Energy*, 45(20), 11395-11408.

Ong, S., Campbell, C., Denholm, P., Margolis, R., and Heath, G., 2013, *Land-use requirements for solar power plants in the United States* (No. NREL/TP-6A20-56290). National Renewable Energy Lab.(NREL), Golden, CO (United States).

Minister of Energy and Mineral Resources Regulation No. 19 of 2016., Pembelian Tenaga Listrik Oleh PT Perusahaan Listrik Negara (Persero).

Rahardjo, I., and Fitriana, I., 2005, Analisis potensi pembangkit listrik tenaga surya di Indonesia. Strategi penyediaan listrik nasional dalam rangka mengantisipasi pemanfaatan PLTU Batubara Skala Kecil, PLTN, dan Energi Terbarukan*. P3TKKE, BPPT, Januari*.

Sahin, M. E., 2020, A photovoltaic powered electrolysis converter system with maximum power point tracking control. *International Journal of Hydrogen Energy*, 45(16), 9293-9304.

Salem, F., and Awadallah, M. A., 2016, Detection and assessment of partial shading in photovoltaic arrays. *Journal of Electrical Systems and Information Technology*, 3(1), 23-32.

Setiawan, I. A., Kumara, I. S., and Sukerayasa, I. W., 2014, Analisis unjuk kerja pembangkit listrik tenaga surya (PLTS) satu MWP terinterkoneksi jaringan di Kayubihi, Bangli. *Majalah Ilmiah Teknologi Elektro*, 13(1).

Sharaf, O. Z., and Orhan, M. F., 2014, An overview of fuel cell technology: Fundamentals and applications. *Renewable and sustainable energy reviews*, 32, 810-853.

Sianipar, R. 2014. *Dasar Perencanaan Pembangkit Listrik Tenaga Surya.* Jakarta, Universitas Trisakti, ISSN 1412-0372.

Simatupang, S., Susilo, B., and Hermanto, M. B., 2012, Rancang bangun dan uji coba solar tracker pada panel surya berbasis mikrokontroler ATMega16. *Jurnal Keteknikan Pertanian Tropis dan Biosistem*, *1*(1), 55-59.

Sofianita, R., Surjosatyo, A., and Siregar, S. R., 2019, Solution concerning climate change and utilization of Wind Turbine and Floating PV in Coastal Area. *ASEAN Journal of Community Engagement*, 3(2), 8.

Stansberry, J., Mejia, A. H., Zhao, L., and Brouwer, J., 2017, Experimental analysis of photovoltaic integration with a proton exchange membrane electrolysis system for power-to-gas. *International Journal of Hydrogen Energy*, 42(52), 30569-30583.

Usman, M.K., 2013, *"Reevaluasi keluaran daya dan optimalisasi pembangkit listrik tenaga hibrid di Kawasan Pantai Baru Pandansimo"*, Program Studi Magister Teknik Sistem, Program Pascasarjana Fakultas Teknik, Universitas Gadjah Mada, Tesis.